

Article

# Investigation of the Most Suitable Conditions for Dehydration of Tuckeroo (*Cupaniopsis anacardioides*) Fruits

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**Abstract:** Tuckeroo (*Cupaniopsis anacardioides*) is an Australian native tree, possessing high level bioactivity and antioxidant activity. To prevent deterioration of active constituents, appropriate drying practices must be determined. This study comparatively evaluates the impact of a range of drying methods including freeze-, microwave-, vacuum-, hot air- and sun-drying on the physical, phytochemical and antioxidant characteristics of Tuckeroo fruit. Experimental results showed that the five drying methods had significant impact on the physicochemical properties and antioxidant activity of the fruits. Of the drying methods assessed, freeze drying best preserved Tuckeroo activity, recording higher total phenolic content (TPC) (81.88 mg gallic acid equivalent (GAE)/g), total flavonoids (TFC) (107.71 mg catechin equivalent (CAE)/g), proanthocyanidins (TPro) (83.86 mg CAE/g) and exhibited the strongest antioxidant capacity. However, vacuum drying at 65 kPa, 100 °C for 5 h is recommended for drying Tuckeroo fruits for further processing in a large scale as it also retained high levels of TPC, TFC and TPro (58 mg GAE/g, 91 mg CAE/g and 74 mg CAE/g, respectively).

**Keywords:** Tuckeroo; drying; fruit; phytochemical; antioxidant; dehydration

## 1. Introduction

Australian flora is both abundant and diverse because of the variability found in climatic zones, which range from temperate to arid tropical. Many medicinal herbs and fruits have been identified by Indigenous Australians and used for treating numerous ailments and diseases including fevers, cold, coughs, pains, inflammation, influenza, headache, diabetes, heart attack and cancer [1–5]. Tuckeroo (*Cupaniopsis anacardioides*) is a tropical Australian native plant which is native to New South Wales, Queensland and Northern Australia. The Tuckeroo plant belongs to the Sapindaceae family [6], which includes other medicinal plants such as *Dimocarpus longan* and *Litchi chinensis*, which are used extensively in China, Taiwan, Korea, Thailand and Vietnam [7,8]. These summer fruiting species possess high bioactivity and antioxidant capacity and are commonly eaten by fruit eating birds such as Australasian figbird, olive-backed oriole and pied currawong [6] and can be consumed by humans [9]. To date, only limited investigations have been conducted into the phytochemical characteristics and medicinal potential of Tuckeroo fruit.

An important step in phytochemical profiling is sample preservation, as it is important that the bioactive constituents present in the sample are well preserved and not subject to denaturing [10,11]. Drying is considered an appropriate preservation technique for a wide variety of herbs or fruits, where short shelf-life, spoilage or short seasonality are concerns. The choice of drying method is an important consideration as drying conditions can have a significant impact on the preservation of biological and antioxidant activity. For example, thermal drying methods (microwave-, oven- and sun-drying) are reported to adversely affect total phenolic content (TPC) and antioxidant activity in the leaves of *Alpinia zerumbet*, *Etligeria elatior*, *Curcuma longa* and *Kaempferia galanga* [12]. By contrast, Dewanto, Wu, Adom and Liu [13] reported the antioxidant activity of tomato increased after heat treatment at 88 °C within 2, 15 and 30 min. A similar trend was found for sweet corn under the commercial processing conditions [14], Shiitake mushroom (*Lentinus edodes*) [15] and ginseng [16]. Additionally, microwave drying was illustrated as the best dehydration method for xao tam phan (*Paramignya trimeria*) roots [10] or for the banana peels [17], whereas vacuum- and hot air-drying were the most suitable for lemon (*Citrus limon*) pomace drying [18], suggesting that the mechanics of the drying process itself impacts differently depending on the presence or absence of direct irradiation, temperature, the physical structure of the plant material itself and the characteristics of the chemical constituents. Therefore, investigation on the impact of different drying methods and conditions for Tuckeroo fruits is needed.

This study aimed to assess the impact of five different drying techniques including freeze drying, sun drying as well as microwave drying, vacuum drying and hot air drying with different conditions on physical, chemical and antioxidant properties of the Tuckeroo fruits to identify the best conditions for preservation of this material for further processing.

## 2. Materials and Methods

### 2.1. Plant Materials

The ripe Tuckeroo (*Cupaniopsis anacardioides*) fruits were collected from nine selected trees in Central Coast (33°21' 13.19" S 151° 22' 23.99" E), New South Wales, Australia, then immediately frozen at −20 °C prior to analysis. These fruits were authenticated by Dr. Anita C. Chalmers, and the voucher specimen (10528) can be found in the Herbarium of the University of Newcastle, NSW, Australia.

### 2.2. Analytical Chemicals

Chemicals used in the experiments conducted were sourced as follows. Methanol, acetone, vanillin and potassium persulfate were purchased from Merck (Darmstadt, Germany). Folin-ciocalteu's phenol reagent, anhydrous sodium carbonate, sodium nitrile, ferric chloride, orthophosphoric acid, neocuproine, 2,4,6-tris(2-pyridyl)-s-triazine, (±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (trolox), 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-azinobis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) were purchased from Sigma-Aldrich Co. (New South Wales, Australia). Copper (II) chloride was obtained from Standard Laboratories (Victoria, Australia). Sodium acetate trihydrate was obtained from Government Stores Department (New South Wales, Australia) Aluminium chloride was obtained from T. Baker Chem. Co. (Phillipsburg, NJ, USA). Ammonium acetate was obtained from BDH Chemicals (Victoria, Australia).

### 2.3. Sample Preparation

Before drying, frozen fresh Tuckeroo fruits (5–7 days stored after harvest) were defrosted overnight at room temperature. The thirty random selected fruits (for each experiment) were then dried to a constant weight using five drying methods including freeze, microwave, vacuum, hot air and sun drying. Samples were weighed at different times using an analytical balance (ATX224, Shimadzu, Philippines) ( $\epsilon = 0.0001$  g) to draw the drying curves for each condition, with the drying time determined once the weight was unchanged. All experiments for each drying condition were conducted in triplicates.

Dried Tuckeroo fruits were ground using a blender (John Morris Scientific, Chatswood, NSW, Australia) and sieved through 1.4 mm mesh (Laboratory test sieve, Endecotts Ltd., London, England). The samples were then extracted in 50% aqueous acetone solvent using an ultrasonic bath (Soniclean, 220 V, 50 Hz and 250 W, Soniclean Pty Ltd., Thebarton, Australia) using the optimal conditions found in our previous study (temperature: 40 °C; timing: 40 min; ultrasonic power: 150 W; sample to solvent ratio: 5 g/100 mL) [19]. The extracts were then centrifuged at 4000 rpm for 10 min at 5 °C (Centrifuge, Beckman J2-MC, Palo Alto, CA, USA) and filtered through a Whatman no. 1 paper to remove unwanted particles for further analysis of total phenolic content (TPC), total flavonoid content (TFC), total proanthocyanidin content (TPro) and antioxidant capacity.

## 2.4. Drying Methods

### 2.4.1. Freeze Drying Method

Thirty random selected Tuckeroo fruits were immersed in liquid nitrogen, placed in a single layer on a stainless steel tray and then freeze dried using an FD3 freeze drier (Thomas Australia Pty. Ltd., Seven Hills, NSW, Australia), with set at vacuum pressure of  $2 \times 10^{-1}$  mbar and temperature of  $-45$  °C for 3 days.

### 2.4.2. Microwave Drying Method

Thirty random selected Tuckeroo fruits were placed on a single layer on the plate of microwave and dried using a microwave oven (Panasonic, model NN-655, Macquarie Park, NSW, Australia). These samples were dried at five different power levels including 240, 480, 720, 960 and 1200 W, interrupted irradiation by turning off every 10 s to avoid burning. At each power level, total microwave drying time including off-time was recorded until consistent weight was achieved.

### 2.4.3. Hot Air Drying Method

Thirty random selected Tuckeroo fruits were placed in a single layer on aluminium trays and dried at five different temperature levels (40, 60, 80, 100 and 120 °C) using a hot air oven (LABEC, Laboratory Equipment Pty Ltd., Marrickville, NSW, Australia). Drying time was recorded when samples reached constant weight.

### 2.4.4. Vacuum Drying Method

Thirty random selected Tuckeroo fruits were placed in a single layer on aluminium trays and dried at five different temperature levels (40, 60, 80, 100 and 120 °C) using a vacuum drier (Thermoline, Australian Marketing Group, Marrickville, NSW, Australia) set at a vacuum pressure of 65 kPa. Drying time was recorded once the samples reached a constant weight.

### 2.4.5. Sun Drying Method

Thirty random selected Tuckeroo fruits were placed within a single layer on a round bamboo basket and dried directly under the sun from 8 am to 4 pm with outside temperature ranging from 32–36.5 °C in the summer time. The samples were stored in the exsiccator between exposure. Drying time was recorded when sample weight was unchanged.

## 2.5. Determination of Physical Properties

Physical properties were determined according to [9,20]. Recovery yield (%) was calculated based on the weight difference before and after drying. Moisture content (%) was determined based on the weight difference after drying Tuckeroo fruits at 110 °C for 12 h. Water activity ( $A_w$ ), which indicates the proportion of free water in the sample, was evaluated using a water activity meter (Pawkit, Decagon Devices, Washington, DC, USA). Extractable solid content (%) of the extracts was measured by drying

the 3 mL filtered extract at 110 °C for 12 h using a hot air oven (LABEC, Laboratory Equipment Pty Ltd., Marrickville, NSW, Australia).

### 2.6. Determination of Bioactive Compounds

Total phenolic content (TPC), total flavonoid content (TFC) and total proanthocyanidins (TPro) were determined using a UV–Vis spectrophotometer (Cary 50 Bio Varian, Australia), as described by Vuong, Hirun, Roach, Bowyer, Phillips and Scarlett [9,21]. TPC was expressed as milligram gallic acid equivalents per gram of dried powder sample (mg GAE/g). TFC and TPro were displayed as milligram catechin equivalents per gram of dried powder sample (CAE/g).

### 2.7. Determination of Antioxidant Capacity of Extracts

Four antioxidant assays, including DPPH (2, 2-Diphenyl-1-Picrylhydrazyl) free radical scavenging activity, ABTS (2, 2'-azinobis-3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging activity, FRAP (ferric reducing antioxidant power) and CUPRAC (cupric ion reducing antioxidant capacity), as described by Thaipong, Boonprakob, Crosby, Cisneros-Zevallos and Byrne [22], Apak, Guclu, Ozyurek and Karademir [23], Pham, Chalmers, Vuong, Bowyer and Scarlett [9], were applied to determine the antioxidant capacity of the Tuckeroo fruit extracts from different drying conditions. The absorbance was measured at 515, 734, 593 and 450 nm, respectively, using a UV–Vis spectrophotometer (Cary 50 Bio Varian, Australia). Trolox was used as a standard for calibration curves and results were expressed as milligram trolox equivalents per gram of dried powder sample (mg TE/g).

### 2.8. Statistical Analysis

SPSS software version 25 was employed, using one-way ANOVA with Duncan's post hoc multiple comparisons test for statistical analysis of the data. Differences between the mean levels from triplicate performance of samples in the variety of drying processes were taken to be statistically significant at  $p < 0.05$ .

Principal components analysis (PCA) was applied to the values of measured components using JMP 14.

## 3. Results and Discussion

### 3.1. Impact of Microwave Drying on Physical, Phytochemical and Antioxidant Properties of Tuckeroo Fruits

This study investigated the impact of different powers at various radiation times and the results (Table 1) indicated that the higher the power that was applied, the less irradiation time was required to dry Tuckeroo to a constant weight. At the lowest power, it took 7 min 10 s, whereas it only took 3 min 10 s when drying at 1200 W. It is obvious because at higher the power, higher the heat was generated inside the sample, therefore the shorter time needed to remove water from the sample.

Physical properties including yield, moisture, water activity and extractable solids were observed to change during the irradiation treatments. Table 1 shows that the recovery yield of dried Tuckeroo did not significantly differ between the power levels ranging from 240 to 960 W; however, it decreased approximately 4% when irradiation was increased to the power level of 1200 W. This can be explained by the various removal rates of moisture when exposed to different heats generated under different conditions. For moisture content, the higher the level of power, the moisture content is lower (except for the power at 720 W). It is similar for water activity. In general, dried fruits with moisture content of less than 10% and water activity of less than 0.5 are suitable for long storage before further processing because of the significantly lesser influence of enzyme and microbial activity.

Extractable solid content is an important parameter of the extraction process because it reflects the quantity of the substances, including nutrient and non-nutrient components, dissolving into solvent and the quantity of powder (extract) obtained after the extraction process. This study found that extractable solids were significantly influenced by different microwave conditions. These can be

explained by the effect of radiation and subsequent heat on both nutrient and non-nutrient components. The results showed the highest percentages of extractable solids (44.10% and 43.67%) were obtained for samples irradiated at 720 W and 240 W, respectively.

The impact of microwave drying conditions on chemical properties is shown in Table 1. In general, radiation time and power significantly affected total phenolic content TPC and their major secondary metabolites (flavonoids (TFC) and proanthocyanidins (TPro)), when irradiated at 960 W and 1200 W. Tuckeroo samples had the higher levels of TPC, TFC, and TPro (54.14 mg GAE/g, 77.9 mg CAE/g, 50.37 mg CAE/g, respectively), at 720 W, but their levels significantly decreased when the power level exceeded 960 W. Levels of TPC, TFC and TPro were approximately 43%, 47% and 28%, respectively, higher than those in the samples treated at 960 W and 1200 W. The deduction of phenolics content and their secondary metabolites at high microwave power might be explained by a disruption of cell wall because of high internal pressure that leads to bond breaking or reformation of heat sensitive biological compounds [24,25]. Antioxidant activity was also highest in the sample treated at 720 W. High levels of radical scavenging activity (DPPH), cupric reducing activity capacity (CUPRAC) and ferric reducing activity power (FRAP) were recorded in samples irradiated at 720 W. These results were slightly different to the findings of the study reported by Vu, Scarlett and Vuong [17] for antioxidant activity present in dried banana peels, which found irradiation at 960 W for 6 min produce the greatest levels of antioxidant activity. The difference can be assumed that individual antioxidant compounds in Tuckeroo fruits are different to those in banana peel, thus they have different susceptibility to various microwave conditions.

Overall, the results reveal that the optimal microwave drying conditions for retaining most of TPC, TFC, TPro and antioxidant activity of Tuckeroo fruits were irradiation for 6 min 10 s at a power of 720 W.

**Table 1.** Impact of microwave drying on physical, phytochemical and antioxidant property of Tuckeroo fruits.

Microwave Power	240 W	480 W	720 W	960 W	1200 W
Irradiation time	7 min 10 s ± 0.05 <sup>a</sup>	7 min 10 s ± 0.05 <sup>a</sup>	6 min 10 s ± 0.02 <sup>b</sup>	5 min 10 s ± 0.02 <sup>c</sup>	3 min 10 s ± 0.02 <sup>d</sup>
<b>Physical properties</b>					
Yield (%)	39.87 ± 1.2 <sup>a</sup>	39.65 ± 1.0 <sup>a</sup>	40.49 ± 1.78 <sup>a</sup>	37.36 ± 3.0 <sup>ab</sup>	35.57 ± 0.31 <sup>b</sup>
Moisture (%)	8.87 ± 0.20 <sup>ab</sup>	8.65 ± 0.01 <sup>b</sup>	9.49 ± 0.71 <sup>a</sup>	6.36 ± 0.63 <sup>c</sup>	4.57 ± 0.02 <sup>d</sup>
Aw	0.47 ± 0.00 <sup>b</sup>	0.46 ± 0.00 <sup>c</sup>	0.48 ± 0.00 <sup>a</sup>	0.44 ± 0.00 <sup>d</sup>	0.38 ± 0.00 <sup>e</sup>
Extractable solid (%)	43.67 ± 0.79 <sup>a</sup>	42.08 ± 1.09 <sup>b</sup>	44.10 ± 0.21 <sup>a</sup>	40.24 ± 0.83 <sup>c</sup>	38.17 ± 0.53 <sup>d</sup>
<b>Phytochemical properties</b>					
TPC (mg GAE/g)	44.89 ± 0.6 <sup>b</sup>	37.9 ± 0.32 <sup>c</sup>	54.14 ± 3.18 <sup>a</sup>	31.78 ± 0.57 <sup>d</sup>	33.51 ± 0.88 <sup>d</sup>
TFC (mg CAE/g)	64.97 ± 0.8 <sup>b</sup>	51.01 ± 0.61 <sup>c</sup>	77.9 ± 1.58 <sup>a</sup>	42.65 ± 2.04 <sup>d</sup>	43.27 ± 0.8 <sup>d</sup>
TPro (mg CAE/g)	50.56 ± 0.38 <sup>a</sup>	42.69 ± 1.13 <sup>b</sup>	50.37 ± 0.87 <sup>a</sup>	36.46 ± 0.55 <sup>c</sup>	37.46 ± 1.61 <sup>c</sup>
<b>Antioxidant properties</b>					
DPPH (mgTE/g)	108.21 ± 0.85 <sup>a</sup>	106.47 ± 0.51 <sup>b</sup>	107.96 ± 0.2 <sup>a</sup>	96.21 ± 0.42 <sup>c</sup>	96.99 ± 0.4 <sup>c</sup>
ABTS (mgTE/g)	156.19 ± 0.15 <sup>b</sup>	140.97 ± 0.54 <sup>c</sup>	176.92 ± 1.49 <sup>a</sup>	103.64 ± 0.6 <sup>e</sup>	116.48 ± 1.54 <sup>d</sup>
FRAP (mgTE/g)	60.0 ± 0.34 <sup>a</sup>	48.2 ± 1.67 <sup>b</sup>	61.19 ± 0.36 <sup>a</sup>	41.11 ± 1.38 <sup>c</sup>	42.78 ± 1.27 <sup>c</sup>
CUPRAC (mgTE/g)	145.11 ± 0.68 <sup>a</sup>	118.71 ± 4.85 <sup>b</sup>	147.49 ± 0.72 <sup>a</sup>	104.75 ± 1.73 <sup>d</sup>	110.66 ± 2.54 <sup>c</sup>

Data are means ± standard deviations ( $n = 3$ ). Data in the same row not sharing similar superscript letters are significantly different at  $p < 0.05$ .

### 3.2. Impact of Vacuum Drying on Physical, Phytochemical and Antioxidant Properties of Tuckeroo Fruits

In this study, the impact of vacuum drying on the physicochemical and antioxidant qualities of Tuckeroo was assessed under different temperature conditions ranging from 40 °C to 120 °C at a pressure of 65 KPa of vacuum pressure.

Results in Table 2 show that increasing drying temperature from 40 °C to 60 °C reduced drying times three fold (from 24 h to 8 h). Moisture extraction was significantly affected by drying temperature, with recovery yield varying from 48.25 ± 1.99 (%) at 20 °C to 34.8 ± 4.56 (%) at 120 °C. Moisture content

and water activity ( $A_w$ ) both similarly diminished with increasing temperature. In contrast, extractable solids rose with temperature increase, peaking at 100 °C (43.45%) before decreasing slightly at 120 °C, suggesting possible degradation of some substances.

For TPC, TFC and TPro, activity rose with drying temperature, peaking at 100 °C (TPC = 57.29 mg GAE/g, TFC = 90.83 mg CAE/g and TPro = 74.0 mg CAE/g) before declining, presumably as a consequence of thermal degradation [26]. Results for antioxidant assays exhibited a similar profile, again peaking at 100 °C before falling away as temperature was further increased.

The results indicate that vacuum drying significantly affects the physical, chemical and antioxidant profile of Tuckeroo fruit. A drying time of 5 h at a temperature of 100 °C was determined to be the optimal sample preparation conditions using the vacuum drying technique.

**Table 2.** Impact of vacuum drying on physicals, phytochemicals and antioxidant property of Tuckeroo fruits.

Temperature (°C)	40	60	80	100	120
Drying time	24 h	8 h	7 h	5 h	4.5 h
<b>Physical properties</b>					
Yield (%)	48.25 ± 1.99 <sup>a</sup>	46.94 ± 4.4 <sup>ab</sup>	41.73 ± 1.83 <sup>bc</sup>	40.8 ± 1.51 <sup>cd</sup>	34.8 ± 4.56 <sup>e</sup>
Moisture (%)	17.25 ± 0.12 <sup>a</sup>	15.94 ± 0.64 <sup>b</sup>	10.73 ± 0.19 <sup>c</sup>	9.8 ± 0.32 <sup>d</sup>	3.8 ± 0.03 <sup>e</sup>
$A_w$	0.55 ± 0.00 <sup>a</sup>	0.53 ± 0.00 <sup>b</sup>	0.49 ± 0.00 <sup>c</sup>	0.48 ± 0.00 <sup>d</sup>	0.32 ± 0.00 <sup>e</sup>
Extractable solid (%)	33.78 ± 1.79 <sup>d</sup>	37.09 ± 2.12 <sup>c</sup>	38.82 ± 1.07 <sup>bc</sup>	43.45 ± 0.61 <sup>a</sup>	40.73 ± 0.16 <sup>b</sup>
<b>Phytochemical properties</b>					
TPC (mg GAE/g)	30.64 ± 1.09 <sup>d</sup>	54.03 ± 0.38 <sup>b</sup>	52.65 ± 0.76 <sup>b</sup>	57.29 ± 1.91 <sup>a</sup>	36.23 ± 2.17 <sup>c</sup>
TFC (mg CAE/g)	56.05 ± 2.26 <sup>d</sup>	74.71 ± 1.26 <sup>c</sup>	83.49 ± 2.7 <sup>b</sup>	90.83 ± 1.92 <sup>a</sup>	44.06 ± 3.59 <sup>e</sup>
TPro (mg CAE/g)	29.78 ± 0.14 <sup>d</sup>	70.41 ± 1.23 <sup>b</sup>	72.91 ± 1.41 <sup>a</sup>	74.0 ± 1.68 <sup>a</sup>	42.14 ± 0.9 <sup>c</sup>
<b>Antioxidant properties</b>					
DPPH (mgTE/g)	94.95 ± 0.7 <sup>c</sup>	108.73 ± 0.34 <sup>a</sup>	108.44 ± 0.16 <sup>a</sup>	108.84 ± 0.2 <sup>a</sup>	103.6 ± 0.58 <sup>b</sup>
ABTS (mgTE/g)	104.67 ± 0.39 <sup>e</sup>	154.82 ± 2.58 <sup>c</sup>	159.98 ± 0.26 <sup>b</sup>	194.64 ± 1.32 <sup>a</sup>	112.5 ± 3.72 <sup>d</sup>
FRAP (mgTE/g)	40.99 ± 1.03 <sup>e</sup>	75.18 ± 1.23 <sup>bc</sup>	76.13 ± 1.61 <sup>ab</sup>	78.76 ± 2.41 <sup>a</sup>	48.48 ± 0.55 <sup>d</sup>
CUPRAC (mgTE/g)	106.11 ± 2.03 <sup>c</sup>	174.00 ± 0.67 <sup>a</sup>	177.33 ± 3.16 <sup>a</sup>	178.49 ± 7.58 <sup>a</sup>	122.07 ± 1.11 <sup>b</sup>

Data are means ± standard deviations ( $n = 3$ ). Data in the same row not sharing similar superscript letters are significantly different at  $p < 0.05$ .

### 3.3. Impact of Hot Air Drying on Physical, Phytochemical and Antioxidant Properties of Tuckeroo Fruits

Hot air drying is a conventional method for food dehydration [27]. Despite disadvantages such as reduced sensory qualities in vegetable products, the technique has a wide acceptance because of its low cost and operational simplicity [28]. In our study, hot air drying was undertaken using temperatures ranging from 40 to 120 °C to assess impact on physicochemical and antioxidant properties.

Results in Table 3 show that drying time to constant weight reduced with increasing temperature. Recovery yield, moisture and  $A_w$  tend to decrease when higher drying temperature was applied, whereas extractable solids slightly increased when drying at higher temperature. TPC, TFC and TPro content generally increased with increasing drying temperature, peaking at 120 °C at values of 50.18 ± 0.29 mg GAE/g, 66.66 ± 2.94 mg CAE/g and 58.28 ± 1.29 mg CAE/g, respectively. Interestingly, the values of TFC was stable during drying temperature tested from 40 up to 100 °C. This outcome attributed that flavonoids were less thermal sensitive than TPC and TPro.

The results from Table 3 also indicate that, the drying conditions significantly affected antioxidant capacity of Tuckeroo. DPPH and ABTS radical scavenging activity, FRAP and CUPRAC were performed, with the highest antioxidant activity under the drying conditions of 120 °C and 3.5 h, followed by those at 40 °C within 25 h drying. From our previous study and the below PCA analysis revealed that antioxidant capacity of Tuckeroo fruits is strongly correlated with phenolic compounds, thus the impact of antioxidant capacity can be explained by the change of phenolic compounds at different hot air drying conditions. An agreement was found in the study on banana peels, that using hot air drying

at 120 °C and 3 h 40 min shown the greatest level of TPC, TFC, TPro and antioxidant activity [17]. Therefore, hot air drying of 120 °C, 3.5 h was selected as the optimal conditions for Tuckeroo fruits.

**Table 3.** Impact of hot air drying on physical, phytochemical and antioxidant properties of Tuckeroo fruits.

Temperature (°C)	40	60	80	100	120
Drying time	25 h	11 h	7 h 20 min	5.5 h	3.5 h
<b>Physical properties</b>					
Yield (%)	45.36 ± 2.57 <sup>a</sup>	34.04 ± 3.68 <sup>c</sup>	40.26 ± 0.26 <sup>b</sup>	40.11 ± 1.44 <sup>b</sup>	35.71 ± 0.38 <sup>c</sup>
Moisture (%)	14.36 ± 0.25 <sup>a</sup>	3.04 ± 0.15 <sup>d</sup>	9.26 ± 0.07 <sup>b</sup>	9.11 ± 0.21 <sup>b</sup>	4.71 ± 0.08 <sup>c</sup>
Aw	0.52 ± 0.00 <sup>a</sup>	0.29 ± 0.00 <sup>d</sup>	0.47 ± 0.00 <sup>b</sup>	0.47 ± 0.00 <sup>b</sup>	0.35 ± 0.00 <sup>c</sup>
Extractable solid (%)	35.07 ± 0.29 <sup>b</sup>	41.23 ± 1.07 <sup>a</sup>	43.25 ± 2.00 <sup>a</sup>	43.01 ± 2.70 <sup>a</sup>	44.04 ± 1.81 <sup>a</sup>
<b>Phytochemical properties</b>					
TPC (mg GAE/g)	39.29 ± 0.67 <sup>b</sup>	31.2 ± 0.69 <sup>d</sup>	36.53 ± 2.64 <sup>c</sup>	35.38 ± 1.49 <sup>c</sup>	50.18 ± 0.29 <sup>a</sup>
TFC (mg CAE/g)	46.18 ± 1.25 <sup>b</sup>	44.1 ± 1.57 <sup>b</sup>	47.2 ± 0.69 <sup>b</sup>	46.36 ± 0.69 <sup>b</sup>	66.66 ± 2.94 <sup>a</sup>
TPro (mg CAE/g)	38.44 ± 0.81 <sup>c</sup>	30.09 ± 0.96 <sup>d</sup>	42.85 ± 0.43 <sup>b</sup>	37.97 ± 0.99 <sup>c</sup>	58.28 ± 1.29 <sup>a</sup>
<b>Antioxidant properties</b>					
DPPH (mg TE/g)	105.93 ± 0.15 <sup>b</sup>	96.94 ± 1.84 <sup>d</sup>	101.96 ± 0.11 <sup>c</sup>	106.54 ± 1.23 <sup>b</sup>	108.67 ± 0.24 <sup>a</sup>
ABTS (mg TE/g)	117.58 ± 0.98 <sup>b</sup>	73.19 ± 3.94 <sup>e</sup>	86.87 ± 3.94 <sup>d</sup>	100.55 ± 4.55 <sup>c</sup>	184.92 ± 3.14 <sup>a</sup>
FRAP (mg TE/g)	53.86 ± 0.33 <sup>b</sup>	42.77 ± 2.44 <sup>d</sup>	47.53 ± 2.78 <sup>c</sup>	49.02 ± 0.65 <sup>c</sup>	72.93 ± 2.34 <sup>a</sup>
CUPRAC (mg TE/g)	132.82 ± 0.65 <sup>b</sup>	112.23 ± 2.83 <sup>e</sup>	117.38 ± 0.73 <sup>d</sup>	123.5 ± 2.33 <sup>c</sup>	168.84 ± 1.08 <sup>a</sup>

Data are means ± standard deviations ( $n = 3$ ). Data in the same row not sharing similar superscript letters are significantly different at  $p < 0.05$ .

#### 3.4. Comparison of the Impact of Different Drying Methods Under Their Optimal Conditions on Physical, Phytochemical and Antioxidant Properties of Tuckeroo Fruits

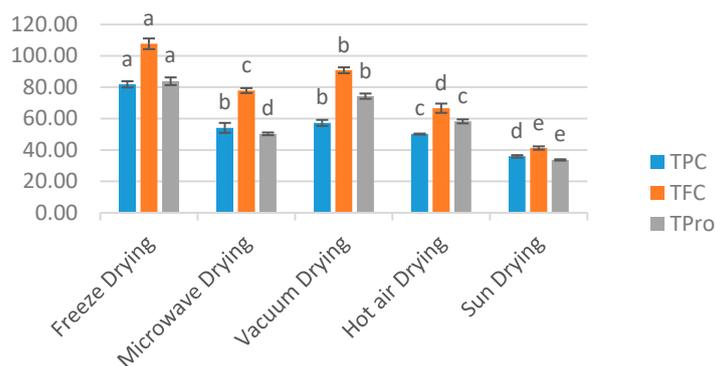
The optimal drying conditions of each drying method were selected for comparison of their impact on physicochemical and antioxidant properties of Tuckeroo fruits. The impact on physical properties is shown in Table 4. As expected, the sun drying technique required the longest time to dry, followed by freeze drying, then vacuum and hot air drying. Microwave drying required a shortest drying time. Sun drying had the greatest recovery yield of  $46.14 \pm 2.21$  (%), followed by vacuum and microwave drying, then hot air, whereas freeze drying had the lowest recovery yield ( $33.79 \pm 0.18$ ), which is approximately 27% lower than that of sun drying. The difference in recovery yields can be explained by the variation of moisture content in samples prepared from different drying methods. The drying method that has higher recovery yield produces samples with higher moisture content, which add more weight on the dried sample. Our study found that sun drying the sample had higher recovery yield, but also had higher moisture content as compared to those prepared from other drying methods. Of note, Tuckeroo fruits dried under the sunlight has high moisture content (15%) and high water activity (0.52), which may be susceptible to degradation due to oxidation and microbial growth, resulting in a shorter product shelf-life [29,30]. Extractable solids were not significantly different between freeze, microwave, vacuum, and hot air drying methods; however, extractable solids were significantly lower when samples were prepared under the sunlight.

**Table 4.** Impact comparison of five different drying methods on physical properties of Tuckeroo fruits.

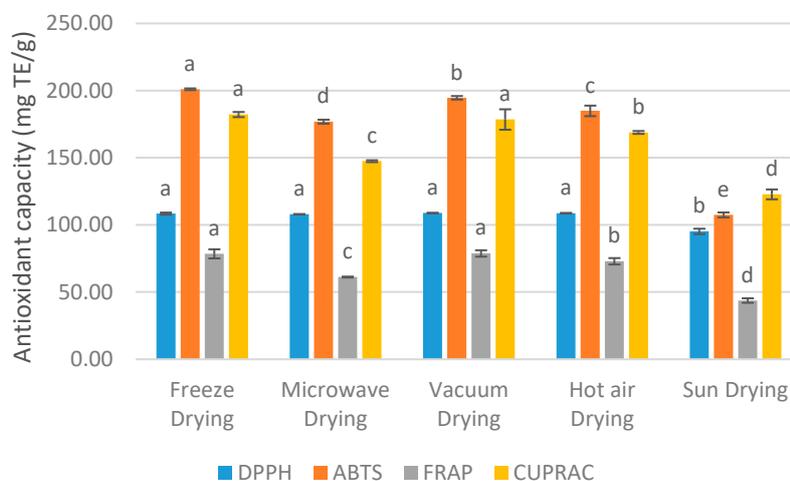
Drying Method	Freeze Drying	Microwave	Vacuum	Hot Air	Sun Drying
Drying conditions	−40 °C, 48 h	720 W, 6 min 10 s	100 °C, 5 h	120 °C, 3.5 h	36.5 °C, 30 h
Yield (%)	33.79 ± 0.18 <sup>d</sup>	40.49 ± 1.78 <sup>b</sup>	40.8 ± 1.51 <sup>b</sup>	35.71 ± 0.38 <sup>c</sup>	46.14 ± 2.21 <sup>a</sup>
Moisture (%)	2.79 ± 0.03 <sup>d</sup>	9.49 ± 0.71 <sup>b</sup>	9.8 ± 0.32 <sup>b</sup>	4.71 ± 0.08 <sup>c</sup>	15.14 ± 0.54 <sup>a</sup>
Aw	0.26 ± 0.00 <sup>d</sup>	0.48 ± 0.00 <sup>b</sup>	0.48 ± 0.00 <sup>b</sup>	0.35 ± 0.00 <sup>c</sup>	0.52 ± 0.00 <sup>a</sup>
Extractable solid (%)	44.62 ± 1.77 <sup>a</sup>	44.10 ± 0.21 <sup>a</sup>	43.45 ± 0.61 <sup>a</sup>	44.04 ± 1.81 <sup>a</sup>	36.92 ± 2.18 <sup>b</sup>

Data are means ± standard deviations ( $n = 3$ ). Data in the same row not sharing similar superscript letters are significantly different at  $p < 0.05$ .

The effects of different drying methods on phytochemical properties Tuckeroo fruits are represented in Figure 1. Freeze drying could retain the largest amount of TPC (81.88 mg GAE/g), TFC (107.71 mg CAE/g) and TPro (83.86 mg CAE/g), followed by vacuum drying (TPC 57.29 mg GAE/g, TFC 90.83 mg CAE/g, TPro 74.3 mg CAE/g), microwave drying (54.14 mg GAE/g, 77.9 mg CAE/g, 50.37 mg CAE/g) and hot air drying (50.18 mg GAE/g, 66.66, 58.28 mg CAE/g, respectively). Sun drying retained the lowest levels of TPC, TFC and TPro (35.96 mg GAE/g = 56 % loss; 41.27 = 62% loss and 33.71 mg CAE/g = 60% loss, respectively). The results also show that drying methods affected antioxidant capacity of Tuckeroo fruits (Figure 2). Among these drying methods, fruits obtained by freeze drying also had the best antioxidant activity, followed by those of vacuum, hot air, microwave and sun drying.



**Figure 1.** Effect of different drying methods on phytochemical properties from Tuckeroo fruit. Data are means  $\pm$  standard deviations ( $n = 3$ ). Data of the bar for each category not sharing similar letters are significantly different at  $p < 0.05$ .



**Figure 2.** Effect of different drying methods on antioxidant properties from Tuckeroo fruit. Data are means  $\pm$  standard deviations ( $n = 3$ ). Data of the bar for each category not sharing similar letters are significantly different at  $p < 0.05$ .

Freeze drying is well known as a reference or control method for drying as it has minimum impact on the sample and generally retains high quantity of the compounds, especially those that are sensitive to heat and oxygen. Freeze drying was found to be the best drying method to preserve sensory and nutrient characteristics of different tropical fruits such as pineapple, Barbados cherry, guava, papaya and mango [31]. Similarly, Tambunan, Yudistira, Kisdiyani and Hernani [32] found that freeze drying retained a greater quality product for ginger and Javanese piper after drying. However, it is costly and time-consuming to use this method for dehydration of plant materials. Therefore, it is necessary to find an alternative method for freeze drying. This study found that vacuum drying can be an alternative option for drying Tuckeroo fruits because vacuum drying required only 5 h, whereas freeze drying

needed 48 h to drying; however, vacuum drying has levels of TPC, TFC and TPro with 30%, 16% and 11%, respectively, less than those of freeze drying.

### 3.5. Visual Relationship Exploration between Different Dehydration Methods, Relevant Phytochemicals and Antioxidant Capacity

PCA was conducted to confirm any relationships among the tested variables (TPC, TFC, TPro, ABTS, DPPH, FRAP and CUPRAC) from different drying conditions. Eigenvalues higher than 80% indicate that the PCA model is reliable for explaining relationship between the tested variables. The PCA model retained two principal components (PC), which explained 94.5% of the total variability. The loading plots of the first two principal components (Figure 3) shows that PC1 and PC 2 correlated positively with DPPH and CUPRAC. PC1 had positive correlation with TPC, TFC, TPro, FRAP and ABTS, whereas, PC2 had negative correlation with these variables.

PCA further confirmed that freeze drying was the best method to retain bioactive compounds and antioxidant properties, followed by vacuum drying at 100 °C and microwave at 720W. These results are consistent with the findings reported in Figures 1 and 2.

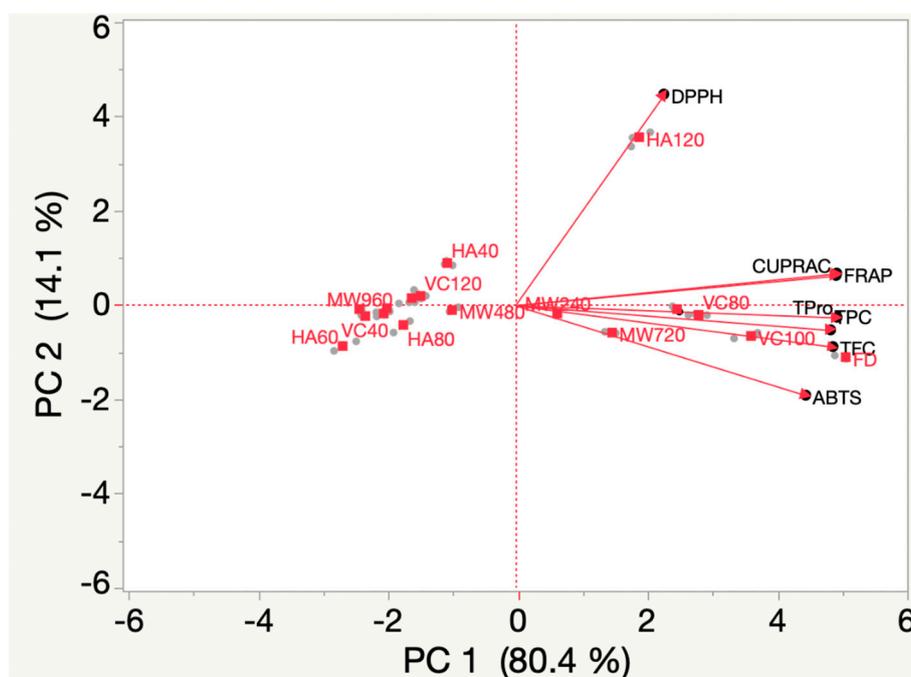


Figure 3. Loading plot for the principal components analysis (PCA) of the first two factors.

## 4. Conclusions

Our findings further confirmed that different drying methods and drying conditions significantly impacted the physical, phytochemical and antioxidant properties of plant materials, including Tuckeroo fruits. The optimal microwave drying conditions for retaining most of TPC, TFC, TPro and antioxidant activity of Tuckeroo fruits were irradiation for 6 min 10 s at a power of 720 W; whereas optimal vacuum drying were found to be 5 h, 100 °C at vacuum pressure of 65 kPa, and hot air drying was 3.5 h at 120 °C. Among the tested drying methods, freeze dried Tuckeroo possessed the greatest physicochemical properties and antioxidant capacity, followed by vacuum and hot air dried fruits, whereas the lowest of those were displayed by sun dried Tuckeroo. However, both freeze and sun drying methods required the longest time to dry. Among the other methods investigated, microwave drying required a short drying time, but retained less phytochemicals and weaker antioxidant activity than vacuum drying at 100 °C for 5 h. Therefore, freeze drying was recommended for preparation of Tuckeroo fruits for future laboratory scale experiments, and vacuum drying is recommended as the second choice for drying

Tuckeroo fruits for further processing and utilisation. As this study only focussed on total phenolic compounds and their second metabolites, future investigations are recommended to study the effect of different drying conditions on individual phenolic compounds and other active compounds, such as carotenoids and vitamins, from the Tuckeroo fruits at both laboratory and industrial scale.

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